ARE YOU SEEING THE FULL SPECTRUM OF POSSIBILITIES?

The many ways you can revamp a vacuum distillation unit (VDU) to unlock your downstream assets

WHITE PAPER
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DO YOU...

...feel constrained by your VDU capacity?

...experience issues maintaining the desired vacuum level in your VDU?

...see metals slip from your VDU unit?

...have concerns about your VDU column and furnace’s run lengths?

...want to lift more vacuum gas oil (VGO) from the crude distillation unit (CDU) to fill downstream units?

...suffer coking issues in the furnace or wash bed?
1. THE SPECTRUM OF REVAMPS THAT CAN UNLOCK YOUR DOWNSTREAM ASSETS

The performance of a VDU and the levels of contaminants in the VGO can have a major bearing on a refinery’s margins, as they can affect the capacity, reliability and cycle length of the hydrocracker, fluidised catalytic cracking or other downstream conversion units.

Fortunately, refiners can cost-effectively improve the performance of their VDU by revamping the unit using Shell’s deep-flash, high-vacuum technology. Indeed, many refiners worldwide have unlocked margin improvements in this way: since 1985, Shell Global Solutions has delivered almost 50 new designs or revamps.

These projects are always driven by the customer’s specific circumstances and objectives, and it is important to understand that they are highly customised initiatives. So, in this white paper, we profile four recent VDU revamps, each of which was driven by a distinct key objective.

These case studies show how customers have:
- increased the capacity of their VDU to provide more hydrocracker feed (Section 4.1);
- enhanced VGO quality to improve downstream reliability (Section 4.2);
- recovered more from the short residue to generate more margin (Section 4.3); and
- improved VDU run length to maximise uptime (Section 4.4).

2. THE ECONOMICS OF A VDU REVAMP

Experience shows that a VDU revamp can unlock substantial value. For example, compared with a typical conventional unit, an 8.9-Mt/y or 150,000-bbl/d unit that uses Shell deep-flash technology can improve a refinery’s margin by some $7.8 million per year.

This is because it can:
- generate 1-3% more distillates;
- cut energy costs by 25%; and
- improve mechanical availability by 1.5%.¹

The capital cost is usually relatively low, the payback time is short, typically a year or less, and the hardware changes are often possible within an existing refinery turnaround window.
3. FIVE KEY VALUE-ADDING DESIGN DIFFERENTIATORS

Shell deep-flash technology has been developed through extensive research on mass transfer and separation equipment, and been supported by operating experience from numerous Shell and Shell-advised units over many years. Indeed, Shell Global Solutions has licensed Shell deep-flash technology in 26 revamped and 24 grassroots units since 1985.

As shown in Figure 1, this technology includes five key design features that can be tailored to meet a refiner’s specific revamp requirements. It is important to note, however, that, because each refiner’s circumstances and business objectives are unique, revamp projects are highly tailored, so, some projects may not incorporate all these design features.

The first of these value-adding design differentiators is Shell proprietary furnace coil design. Conventional technologies can be prone to coking, but Shell Global Solutions has developed technology involving suppressed vaporisation that controls the flow regime in a furnace. The liquid coats the walls of the heated coils continuously throughout the furnace and the vapour passes through the core, thereby completely avoiding a mist flow region where the droplets can hit the very hot walls and form coke. Consequently, Shell-designed units typically achieve pacesetting cycle lengths (Figure 2).
Shell Global Solutions

FIGURE 2: Many Shell-designed units run for four or more years before decoking is required.

Shell direct-contact spray condensation sections also contribute to improved distillate recovery. Conventional VDUs often have packed pumparound condensation sections, but this packing can increase pressure drop and reduce yields. The Shell approach is to achieve vapour condensation by direct contact with liquid in an empty space. This removes the need for packing and reduces column height. Crucially, it also maximises distillate recovery, as the pressure drop is lower than for packed condensation sections, thus enabling lower flash-zone pressures.

Entrainment of vacuum residue (VR) from the flash zone often limits the VGO yield of conventional VDUs owing to quality concerns. To address this, the proprietary Shell Schoepentoechter Plus vane-type feed inlet device is designed to achieve a high de-entrainment efficiency at a lower pressure drop than conventional feed inlet devices. It also offers good vapour distribution. This highly efficient feed inlet device can help operators to process more difficult crudes and meet tighter product specifications.

Coking of the wash oil section, which washes down the remnants of entrained VR, is a common reason for premature VDU shutdowns. Shell-designed wash oil sections and wash rate management aim to avoid coking and, thus, extend cycle lengths, increase distillate yields and meet tighter product specifications. Maintaining a low pressure drop across the wash oil section is key to this: conventional designs may see a gradual increase in pressure drop over the wash oil packing due to coking, which can cause deterioration in distillate yield and quality.

Based on its operating experience, Shell Global Solutions has developed guidelines for the design and operation of wash oil beds that can enable continuous operation for over four years without coking of the wash oil packing. As shown in Figure 3, Shell-designed and advised units can typically operate for over four years without coking of the wash oil bed packing.
FIGURE 3: Shell-designed and advised units can typically operate for more than four years without coking of the wash oil bed packing.

Shell low-pressure-drop insulated draw-off trays help to maximise VGO yield by:
- having minimum liquid holdup on the tray to avoid coking;
- insulating the bottom trays to minimise condensation of hot vapour, i.e., wild reflux, against the relatively cold tray surface by having an empty space between double walls; and
- leaving large open areas for vapour passage and thus providing a very low pressure drop, good vapour distribution and a lower flash-zone pressure.

In addition, the draw-off trays’ shallow design helps to reduce the column height, thereby saving capital costs, and makes them easy to install because they do not require seal welding.
4. CASE STUDIES

4.1 Increasing VDU capacity to provide more hydrocracker feed

Situation
A South Korean refiner planned to create a new 20,000-bbl/d lubricant base oil plant that would take unconverted oil from the hydrocracker. To meet the targeted yield of lubricant base oil, it was necessary to revamp the hydrocracker to increase its throughput by about 10%. In addition, it was vital to produce additional feedstock for the hydrocracker by going further back into the processing stream and revamping the VDU.

The objectives of the VDU revamp were to increase the VGO yield from 30,000 to 35,000 bbl/d and ensure suitable quality VGO for hydrocracker feedstock. The changes made to the refinery configuration during this project are shown in Figure 4.

Solution
As part of the pre-revamp feasibility study, several options were studied in detail to achieve the target VGO yield. Shell Global Solutions then conducted cost–benefit analyses on these options. The refiner selected the option that involved the largest revamp, as this was the lowest-capital-cost option. However, it was also the most technically challenging, as it involved extensive modifications of the existing units resulting in complex implementation.

The key changes were:
- **revamping the furnaces to increase their duty** by adding tubes in the convection section and switching completely to gas firing instead of dual-fuel firing;
- **replacing the existing vapour horn type feed inlet device** with a Shell Schoepentoeter Plus inlet device to reduce the entrainment of VR to VGO and to ensure better vapour distribution; and
- **upscaled the transfer line and the column feed inlet nozzle** to limit the velocity of the two-phase flow in the transfer line below the sonic velocity limit and thus ensure the mechanical stability of the transfer line and efficient de-entrainment performance of the inlet device.

Working closely with site staff, Shell Global Solutions also took all possible steps to minimise the vacuum column pressure drop to help maximise distillate yield. The pumparound and wash bed packing were replaced with the latest-generation, low-pressure-drop structured packing and the existing chimney trays were replaced with proprietary Shell low-pressure-drop draw-off trays.

The team also installed new spray distributors and made minor plant modifications outside the column to support the main revamp, including upgrading the heat exchangers and pumps.

During the period from concept development to commissioning, Shell Global Solutions remained closely engaged with the client for successful on-time completion of this complex project. A subsequent performance test run confirmed that all the revamp targets had been met. The improvement is quality parameters is shown in Table 1.

<table>
<thead>
<tr>
<th>VGO QUALITY PARAMETER</th>
<th>BEFORE REVAMP</th>
<th>AFTER REVAMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1160 T95%, °C</td>
<td>540</td>
<td>562</td>
</tr>
<tr>
<td>Nickel + vanadium, wppm</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Conradson carbon residue, wt%</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**TABLE 1**: How the revamp changed the VGO product qualities.
Value delivered

The project’s economics were highly attractive. The cost of the modifications and the additional downtime required for implementation was about $26 million, and the additional VGO that the revamp unlocked increased margins by about $46 million per year. The simple payback period, therefore, was less than one year.

FIGURE 4: The refinery block scheme before (left) and after (right) the VDU revamp. Before the revamp, the refinery had an open-art VDU and a non-Shell-licensed hydrocracker. The project introduced a Shell-licensed deep-flash VDU and hydrocracker, and a new lubricant base oil unit.

THE PROJECT AT A GLANCE

Project: South Korean refinery, VDU revamp
Objective: Increase VGO capacity, ensure suitable VGO quality
Key changes: Furnace revamp; Shell Schoepentoeter Plus inlet device; transfer line upscaling; column feed inlet nozzle upscaling
Benefit: $46 million margin increase, less than one year payback period
4.2 Enhancing VGO quality to improve downstream reliability

**Situation**
An Indian refiner wanted to unlock more barrels of VGO from its 18,000-t/d CDU. For this project, however, it was found that changes to the furnace were unnecessary and most of the packing could stay. There was already sufficient capacity in the column, furnace and transfer line, and modifications were only required to the wash oil section internals and the feed inlet device. Consequently, this was a minimum capital expenditure revamp.

The refiner’s previous attempts to increase the VGO yield had resulted in high metals contamination. Investigations identified several potential causes, including:
- the feed entry device was not doing enough to de-entrain the VR from the VGO;
- the velocity in the transfer line was high; and
- the VR entrainment in the slop cut and the wash oil rates both exceeded Shell guidelines.

**Solution**
Shell Global Solutions proposed three main actions to improve the situation:
1. Recycle the vacuum slops to the VDU furnace for reprocessing and recovering additional VGO.
2. Install a Shell Schoepentoeter Plus feed inlet device to improve the VR de-entrainment performance.
3. Install the Shell proprietary wash bed configuration to minimise the wash oil rate to maximise the VGO recovery with acceptable quality for downstream units.

**Value delivered**
The modifications were implemented during a turnaround window. The data from a test run then enabled the VGO increase to be calculated. After derating, which was necessary to adjust for a change in feed quality and because the plant operates in bituminous mode for eight months of the year, the average annual VGO benefit was calculated to be 1.5 wt% on crude throughput (263 t/d of additional VGO on a crude throughput of 18,000 t/d). Given the enhanced value of VGO compared with that of VR, this had a major impact on the refiner’s margins.

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**THE PROJECT AT A GLANCE**
- **Project:** Indian refinery, CDU revamp
- **Objective:** Increase VGO capacity
- **Key changes:** Recycle vacuum slops to the VDU furnace; Shell Schoepentoeter Plus inlet device; Shell proprietary wash bed configuration
- **Benefit:** 1.5 wt% (on crude throughput) increase in annual VGO yield

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4.3 Recovering more waxy distillates from the short residue to generate more margin

**Situation**
A refiner in Asia Pacific intended to increase its hydrocracking capacity, which would require additional waxy distillate production. Its vacuum distillation column was operating at relatively mild flash zone conditions that resulted in a significant quantity of valuable 550°C minus content (hydrocracker feedstock material) being lost to the short residue.
Solution
In 2009, Shell Global Solutions studied several debottlenecking options for recovering additional waxy distillates. These included either revamping or replacing the existing furnace and column and installing a new furnace and column in either parallel or series. After a thorough evaluation, the refiner selected the option of processing the short residue from the existing unit under deep-flash conditions in a new furnace and high-vacuum column, which would be in series with the existing vacuum column. This option scored better than the others in terms of capital expenditure, shutdown time and operational flexibility.

In 2010, Shell Global Solutions delivered the basic design package for the new unit: a vacuum furnace, a high-vacuum column and the associated equipment. The unit was designed to recover 54 wt% of short residue feed as additional waxy distillate while maintaining the product quality specifications and minimising cracking of the feedstock. The design challenge was to meet the distillate recovery and quality targets because the short residue feed was heavier and contained a higher concentration of contaminants compared with typical feeds to VDUs.

Several innovative features were introduced, especially around the steam stripping section design, and the Shell Schoepentoeter Plus was introduced as feed inlet device. The new furnace was designed to ensure a minimum decoking interval of three years. The furnace and the column function are designed to function well under a wide variation in feed quality.

As shown in Figure 5, the short residue from the existing VDU contains a significant amount of 550°C minus content, which is recovered in the new high-vacuum unit (HVU).

Despite the unit’s technical complexity, the final package was delivered within a tight time frame of 12 weeks.

FIGURE 5: The new HVU recovers the valuable 550°C minus VGO material that was previously lost.
Value delivered
In 2014, the unit was successfully commissioned. Its capacity, turndown operability and waxy distillate and short residue qualities and properties were found to be achievable and sustainable.

THE PROJECT AT A GLANCE
Project: Asia-Pacific refinery, VDU revamp
Objective: Increase waxy distillate production
Key changes: Changes to the steam stripping section; Shell Schoepentoeter Plus inlet device
Benefit: The recovery of valuable 550°C minus VGO material from short residue

4.4 Improving VDU run length to maximise uptime

Situation
A refiner in South East Asia intended to revamp its VDU to achieve a minimum run length of three years to match the hydrocracker shutdown cycle. Owing to frequent fouling of the vacuum column wash section, the run length of the unit could not be extended beyond two to two and a half years.

Solution
In the first phase, Shell Global Solutions carried out a study to identify the revamp requirements to achieve the desired run length and helped the refiner make a preliminary estimate of the cost associated with the revamp.

Subsequently, Shell Global Solutions delivered a basic design package for the modifications of the vacuum column and associated equipment. In addition to the target of increased run length, other revamp targets were set during the basic design, including unit throughput, VGO and waxy distillate yield and quality, and achievable depth of flash at the end of a three-year run length. The key modifications suggested for the column were to convert the existing two-stage wash section into a single-stage wash section and to replace the existing feed inlet device with a Shell Schoepentoeter Plus device.

Value delivered
The design package was delivered in September 2014. Shell Global Solutions supported the refiner throughout the implementation stages, especially during the installation and start-up activities in June 2016. The performance test run of the revamped unit was carried out in August 2016. From the performance test run data analysis, it was concluded and accepted by the refiner that all the revamp targets had been achieved. The targets for the three-year run length and the depth of flash at the end of the three-year cycle will be assessed at the end of run.

THE PROJECT AT A GLANCE
Project: South East Asia refinery, VDU revamp
Objective: Increase VDU run length (frequent fouling of the vacuum column wash section had been a key constraint)
Key changes: Convert the wash section from two stage to single stage; Shell Schoepentoeter Plus inlet device
Benefit: Unit run length extended to three years or more
5. BENCHMARKING DATA PROVES THE VALUE OF LEADING-EDGE TECHNOLOGY

According to Shell 2008 international benchmarking studies, by using Shell technology, customers are benefiting from:

- **higher VGO recovery.** Whereas conventionally designed units have flash zone pressures of about 30 mmHg, about half the Shell designed and operated vacuum units have flash zone pressures of 20 mm Hg or less, as shown in Figure 6. Lower flash zone pressures mean higher VGO recovery.

- **enhanced reliability.** Shell’s design and operating practices for furnaces and wash oil sections have effectively resolved coking in these areas, which are two main causes of unscheduled HVU shutdowns. As shown in Figure 7, of the Shell designed and advised vacuum units, all but one site is above the industry average and most are within the first quartile. Mechanical availability is 2% higher than the industry average.

- **long cycle length.** As shown in Figure 8, many of the Shell designed and advised vacuum units have cycles of four or more years (at some sites the cycle length is dictated by the downstream conversion units).

- **improved yield.** Whereas conventionally designed units typically have cut points in the range 535–565°C, many of the Shell designed and advised deep-flash vacuum units have cut points over 575°C, and some over 600°C, as shown in Figure 9.

![Figure 6](image1.png)  
**FIGURE 6:** About half of the Shell designed and operated vacuum units have flash zone pressures of 20 mm Hg or less.

![Figure 7](image2.png)  
**FIGURE 7:** All but one of the Shell designed and operated vacuum units are above the industry average for mechanical reliability.
6. WHY CHOOSE SHELL?

**VDU revamps can often be very challenging, so, if they are not engineered properly, it may be impossible to meet the desired revamp objectives. Experience and leading-edge technology are key to a successful, value-adding project.**

**Shell is an owner-operator**

As well as being an oil and gas technology licensor, Shell also operates its own plants, so the operational feedback we receive from these assets helps to provide special insights into the challenges that our customers are facing. We also ensure that we incorporate the lessons learned from these plants into our design practices.

**Track record**

Since 1985, we have licensed Shell deep-flash high-vacuum technology in 26 revamped units, see the table opposite.
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**CUSTOMISED SOLUTIONS**

At Shell Global Solutions, we believe that the most appropriate solution for a specific customer will always be a customised one. We have, therefore, developed our own approach to technical collaboration – we call it co-creation – in which our consultants and technologists work closely with our customers to identify and evaluate the best options and solutions to meet their business objectives.

**LEADING-EDGE TECHNOLOGY**

Benchmarking studies have shown that the technology solutions that we deploy through a VDU revamp, which include the Shell Schoepentoeter Plus device, can help customers to increase VGO recovery, reliability, cycle length and yield.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>START-UP</th>
<th>CAPACITY, T/D</th>
<th>FEEDSTOCK</th>
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<tbody>
<tr>
<td>Thailand</td>
<td>2016</td>
<td>10,000</td>
<td>Various blend</td>
</tr>
<tr>
<td>South Korea</td>
<td>2014</td>
<td>12,000</td>
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<tr>
<td>India</td>
<td>2013</td>
<td>9,300</td>
<td>Arab light/heavy</td>
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<tr>
<td>Greece</td>
<td>2010</td>
<td>8,400</td>
<td>Middle East</td>
</tr>
<tr>
<td>Thailand</td>
<td>2006</td>
<td>6,300</td>
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</tr>
<tr>
<td>India</td>
<td>2004</td>
<td>47,000</td>
<td>Arab heavy/Maya</td>
</tr>
<tr>
<td>India</td>
<td>2003</td>
<td>47,000</td>
<td>Arab heavy/Maya</td>
</tr>
<tr>
<td>USA</td>
<td>2002</td>
<td>13,500</td>
<td>West America</td>
</tr>
<tr>
<td>Sweden</td>
<td>2002</td>
<td>10,600</td>
<td>Gullfaks/Troll</td>
</tr>
<tr>
<td>Italy</td>
<td>2002</td>
<td>5,800</td>
<td>Arab heavy</td>
</tr>
<tr>
<td>India</td>
<td>2002</td>
<td>22,000</td>
<td>Arab light/heavy</td>
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<td>2000</td>
<td>3,500</td>
<td>North Sea</td>
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<tr>
<td>Italy</td>
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<td>1998</td>
<td>7,500</td>
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<td>5,400</td>
<td>Arab light</td>
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<td>Germany</td>
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<td>4,500</td>
<td>Ekofisk</td>
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<td>Thailand</td>
<td>1994</td>
<td>6,400</td>
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<td>5,000</td>
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<td>9,000</td>
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<tr>
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</tr>
<tr>
<td>Switzerland</td>
<td>1985</td>
<td>4,600</td>
<td>Arab heavy</td>
</tr>
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</table>

**7. KEY TAKEAWAYS**

- Refiners can unlock their downstream assets by increasing VDU capacity and reliability, while also controlling contaminant levels to within the conversion units’ acceptability limits, by revamping the unit using Shell deep-flash technology.
- The four case studies described in this white paper demonstrate that these are highly customised projects and can be driven by a wide range of business objectives.
- Such projects can generate substantial value. For example, compared with a typical conventional unit, an 8.9-Mt/y or 150,000-bbl/d unit that uses Shell deep-flash technology can improve a refinery’s margin by $7.8 million per year.
- The capital cost is usually relatively low, the payback time is short, typically a year or less, and the hardware changes are often possible within an existing refinery turnaround window.
- VDU revamps can often be very challenging, so, if they are not engineered properly, it may be impossible to meet the desired revamp objectives. Since 1985, Shell Global Solutions has delivered almost 50 new designs or revamps and the organisation leverages that track record, as well as its owner–operator experience, to help deliver successful, value-adding projects.
ABOUT US

Shell Global Solutions provides technical consultancy and licensed technologies for Shell and third-party customers within the energy industry. Shell Global Solutions strives to deliver innovative technical solutions and effective technology to support its customers in their day-to-day operations and delivery of strategic plans. This support enables customers to improve the capacity and performance of existing units; integrate new process units into existing refineries and petrochemical complexes; incorporate advanced proprietary catalyst systems (Criterion) and reactor internals; and design grassroots refineries.

Shell Global Solutions is affiliated with Shell’s catalyst companies, which innovate and sell catalysts through a network that includes Criterion Catalysts & Technologies, Zeolyst International, CRI Catalyst Company and CRI Leuna (formerly known as Kataleuna).

For further information, please visit our website at www.shell.com/globalsolutions.

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